THE VITREOUS BODY

ITS ORIGIN, DEVELOPMENT, AND STRUCTURE
AS OBSERVED IN THE EYE OF THE PIG

BY

ALOISIUS WILLIAM FROMM, O. F. M.

Thesis submitted to the Faculty of Sciences of the Catholic University of America, in partial fulfillment of the requirements for the degree of Doctor of Philosophy

WASHINGTON, D. C.

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INTRODUCTION

The origin of the vitreous body of the eye has long been in doubt. Even the numerous and thorough investigations of the first decade of the present century, although clearing up many difficulties and correcting false notions, have failed to bring a satisfactory answer to the question, "Is the vitreous body of the eye a derivative of the outer or middle germ layer; is it an ectodermal or mesodermal formation?" A glance at some of the latest and most widely used textbooks, chosen at random, reveals the uncertainty existing among modern authors as to the origin of this interesting structure of the eye. Says Parker (page 113), "Mesoderm also makes its way into the optic cup, through the choroid fissure, and becomes the vitreous humour." Lillie, on the other hand, maintains (page 275) the "researches of the last few years have demonstrated that the vitreous body is primarily of ectodermal origin, its fibers arising as processes of cells of the inner layer of the optic cup and the matrix as secretion." Again, Prentiss and Arey assert (page 381) that "the vitreous body may be regarded as a derivative both of the ectoderm and the mesoderm."

The reasons for this diversity of opinion among biologists may be reduced to the following: 1. The very delicate nature of the vitreous body, which differs so widely from all other tissues, renders its study extremely difficult. It requires special methods of technique not ordinarily employed in histological investigations. The difficulties of obtaining perfect sections of the eye in all its stages of development have been regarded by some investigators as almost insurmountable; 2. The extreme complexity of the mammalian eye, its very rapid development, especially in early embryonic life, the appearance and disappearance of an intricate vascular system in the course of development with its concomitant radical changes—all this obscures the origin and growth of the vitreous body and renders its study as difficult as it is interesting. The vast changes, which follow one another in rapid succession, make it wellnigh impossible

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to forecast with any degree of certainty later developments. The study of the entire embryonic history of the eye alone can solve the mysteries of the origin, the development, and the structure of the vitreous body. It goes without saying that the study of the fully developed eye does not throw much light upon the origin and development of its parts.

To attempt a solution of the problem by methods not heretofore employed in this matter, is the purpose of this work. If further justification for reopening the discussion were needed, we might point to the not very creditable fact that, to our knowledge, no special treatise on this subject exists in the English language.

It was at first planned to make this study comparative, but a closer acquaintance with the work already done made it appear more advisable to investigate the development of the vitreous body of one species from the earliest beginning to its adult condition. The species that was finally selected is the pig, principally on account of the facility of obtaining a complete series of embryonic eyes. More than one hundred and fifty specimens, representing all stages of development, were examined. The material was obtained from the local abattoir. A few specimens were given me by my former teacher, Dr. Carl R. Moore, of the University of Chicago, to whom I extend here my sincere thanks for his interest in the success of this work. Acknowledgment of indebtedness is also made to Professor J. B. Parker, Ph. D., and Mr. G. J. Brilmyer, M. S., of the Catholic University of America, under whose guidance these investigations were made; to Fr. Mahan, S. J., and Dr. T. T. Job, of Loyola Medical School, Chicago, who kindly permitted me the use of their laboratory in the summer of 1920, and to Fr. Victor Herring, O. F. M., for preparing most of the sketches.

HISTORICAL SKETCH

The history of the origin of the vitreous body of the eye dates back to the year 1848, when H. Schöler submitted to the University of Dorpat an inaugural dissertation embodying his observations on the development of the chick's eye. Schöler was the first to notice that very early in the development of the chick a very delicate tissue of mesoderm, *pars systematis cutis,* enters the optic cup through the choroid fissure. Finding no other elements present, Schöler naturally attributed to this portion of the middle germ

layer the origin of the vitreous body. Schöler, therefore, must be credited with the enunciation of the theory which later was to be known as the Theory of the Mesodermic Origin of the Vitreous Body.

This theory became more generally known when R. Virchow, in 1852, reviewed Schöler's work, approved it, and classified the vitreous body, which had always defied classification, as a special kind of connective tissue. A. v. Kölliker, in 1861, also accepted the new theory, and his authority blazed the way for Schöler's views, which thenceforth dominated biological circles almost to the end of the last century and which find defenders even now.

While all these authors agree as to the mesodermic origin of the vitreous body, they differ widely in determining more precisely the portion of the mesoblast genetically responsible for this tissue. Most of them, following Schöler, derive the vitreous body from the mesoderm entering the optic cup through the choroid fissure. This view seems to be based largely on the observations made in the development of the chick's eye, in which other mesoblastic elements are very scarce. Other investigators have called attention to the relatively large circular opening between the lens and the inner layer of the retina and the continuity of the extra-ocular mesenchyme with the vitreous body. Thus Van Pée attributes the origin of a portion of the vitreous fibers to the mesenchyme surrounding the optic cup on all sides and entering through the perilenticular opening. But the most conflicting statements are made by the defenders of the mesodermic origin regarding the very thin layer of mesenchyme originally found between the optic vesicle and the body ectoderm. Kölliker at first thought it probable that during the formation of the lens a part of this mesoderm is carried into the optic cup and gives rise to the *tunica vasculosa lentis.* Later, however, he began to doubt the correctness of this view. Arnold is more emphatic in attributing the origin of the vitreous body exclusively to this portion of the mesoderm. On the other hand, Cirincione, the most ardent defender of the mesodermic origin of the vitreous body, rejects these explanations and returns to Schöler's more generally accepted views.

The first to challenge the theory of the mesodermic origin of the vitreous body was L. Kessler, who, in 1871, made an exhaustive study of the development of the chick's eye, and came to the conclusion that the vitreous body is an amorphous gelatinous mass, formed as

an exudation from the blood vessels, into which a few migratory cells or leucocytes had found their way. The theory of Kessler, known as the Transudation Theory, found little favor with scientists.

A more generous reception was accorded to a new theory proposed by Tornatola at the International Congress of Anatomists, held in Moscow, in 1897. Tornatola asserted that the vitreous body in vertebrates is essentially a fibrous substance, derived exclusively from the retinal cells, and hence an ectodermal formation. His Theory of the Ectodermic Origin of the Vitreous Body found many defenders, such as Rabl, Fischel, Addario, Wolfrum, v. Szily, Mavas, Magitot, Seefelder, and others. According to this theory, the structural parts of the vitreous body consist of a network of very delicate fibers, that have their origin in the supporting cells of the retina and hence are ectodermal. The mesoderm elements are thought to be either leucocytes or true mesoderm cells, having, however, only vaso-formative or nutritive functions and in no way contributing to the production of the vitreous body.

Lenhossék, in 1902, while admitting the ectodermic origin of the vitreous body, attributed it exclusively to the lens cells and proposed his Theory of the Lenticular Origin of the Vitreous Body.

To reconcile these conflicting opinions, Van Pée and v. Kölliker almost simultaneously expressed the view that the fibrous portions of the vitreous body must be regarded as a complex tissue, to which both ectoderm and mesoderm contribute. According to both these investigators, some of the vitreous fibers originate from the cells of the retina, while the rest are the product either of the extra-ocular mesenchyme (Van Pée) or of the extensive vascular system which is found at certain stages in the development of all mammalian eyes (Kölliker).

METHODS

The extreme delicacy of the structure of the vitreous body makes the question of method all-important. Indeed, diversity of opinion regarding the origin, the development, and the structure of this tissue is owing, in large measure, to the methods used.

In the earlier stages of development, including embryos of 25 mm length, most of the ordinary killing fluids were found serviceable, Zenker's, Bouin's, and Schaffner's being most frequently used.

The embryos were removed from the uterus and immediately placed into the killing fluid, which had been warmed to about body temperature. Smaller embryos were fixed in toto; in larger specimens the head was removed and sometimes cut longitudinally to permit uniform penetration. The material was left in the fluids at least twenty-four hours. Dehydration was effected by means of alcohol, the material being passed through the usual grades of 25%, 35%, etc., to absolute alcohol. It was then cleared in xylol or cedar oil, the latter being preferred, because it clears readily from 95% alcohol and because it prevents the tissues from becoming too brittle. After being cleared, the tissue was embedded in paraffin. Sections were cut in various thicknesses, 6, 8, 10, 15, and 25 microns. For the study of the fibrous parts of the vitreous body, thick sections are generally to be preferred. A number of sections were mounted without the aid of a fixative to eliminate, as far as possible, all foreign material from the sections, a perfectly clean slide and careful handling being necessary to bring about the desired results. The fibers of the vitreous body are susceptible of almost all stains. Good results were obtained with fuchsin, borax-carmine, Mallory's connective tissue stain, Delafield's haematoxylin, Heidenhain's iron-alum-haematoxylin with or without an additional slight stain of eosin or erythrosin. Overstaining was resorted to in a few cases to bring out the finer connections between the fibers. A heavy stain greatly facilitates the study of this delicate tissue. No material was stained in bulk, thus insuring a uniform stain.

This method was found unsuited to embryos of more than 35 mm. The action of the alcohol used in dehydration, and the heat necessary for paraffin embedding caused greater or smaller shrinkage of the vitreous fibers, while the subsequent removal of the paraffin almost invariably led to a collapse of the delicate fibrous framework of the vitreous body. For larger embryos a new method, first described by Szent-Györgyi, with some modifications, was found to give excellent results.

As killing and fixing fluid the following mixture was used: acetone 125 cc, formalin 40 cc, acetic acid 5 cc, water 100 cc, mercuric chloride 4 g. The eyes were carefully removed from their sockets, freed of all adhering tissue, plunged into the killing fluid, which had been heated to body temperature, and left in the fluid from five to seven days, according to their size. Then to every 100 cc of the fluid 50 cc of concentrated acetone were added and the eyes

left for an additional two to four days. Without being washed, they were then transferred to concentrated acetone for two to three days. To facilitate dehydration, a layer of calcium chloride was spread in the bottom of the vessel. To prevent a too violent action of the calcium chloride on the eyes, direct contact between the two must be avoided. The material was then placed for twenty-four hours in ether-alcohol, and thereafter embedded. Embedding was done in celloidin or paralodion, dissolved in ether-alcohol, smaller eyes being placed successively in 2, 5, 8, and 10% solution, larger eyes in 1, 3, 5, and 8% solution, remaining in each about three days. Parts of the coats of the eyes were removed before embedding to insure perfect penetration. Hardening was done by means of chloroform and terpineol. Sections were cut very thick, 100, 150, 200, 250, and 300 microns. They were placed into a 95% alcoholic solution of iodin to remove the mercuric chloride crystals, then into 75% alcohol and, immediately before staining, into distilled water. Various stains were tried, the best results being obtained with Held's molybdic haematoxylin (haematox. cryst. 1 g., molybdic acid 10 g., 70% alcohol 100 cc). The stain was permitted to ripen about three weeks, carefully decanted and, before use, diluted with ten times its volume of distilled water. The sections were then passed through the various grades of alcohol to 95%, cleared in carbol-xylol, and mounted in balsam. The structure and arrangement of the fibrous part of the vitreous body were brought out with remarkable clearness in this way, but, unfortunately, the remaining structures were deeply overstained. To remedy this defect, some sections were stained in Lyons Blue, but with indifferent success.

INVESTIGATION

I Primitive Vitreous Body

The period of development forming the object of this part of our investigation, includes embryos ranging from 4 to 11 mm in length and shows the origin and growth of the eye from its beginning to the completion of the optic cup and the lens vesicle, before the appearance of blood vessels in the cavity of the vitreous body. It shows the latter in its primitive and simplest form, not obscured by the numerous mesodermal elements, which later render its study more difficult.

In embryos of 4, 5, and 6 mm, we witness the origin of the eye. The primary optic vesicle gradually invaginates to form the optic cup, the overlying body ectoderm thickens and bends inward to give rise to the lens vesicle. Cup and lens are in close contact throughout; no mesoderm is found between them (Figure 6). The cavity of the vitreous body, the posterior chamber of the eye, is absent in the younger specimens, but appears as a narrow slit between future retina and lens in the 6 mm embryo. The development thenceforth is very rapid, and in the 11 mm embryo, the structure of the eye may be described thus: the optic cup is complete, consisting of an inner layer, the retina, and an outer, the pigment layer. The former shows two distinct regions, a cellular, and the so-called mantle layer. Nerve fibers and pigment are still absent. The lens vesicle has separated from the body ectoderm. The choroid fissure is wide open, and the surrounding mesoderm is pressing up into the fissure (Figure 3), but has not yet penetrated into the optic cup. The optic stalk, an open tube with wide lumen, can easily be traced to the diencephalon.

The cavity of the vitreous body is still narrow. It contains no blood vessels and only a few cells scattered here and there. The origin and the nature of these cells have not been satisfactorily explained. Some authors, as v. Lenhossék, consider them the remnants of the thin layer of mesoderm originally found between the optic vesicle and the body ectoderm, and carried into the optic cup by the invaginating lens placode. Others, among whom are Seefelder, Mavas, and Magitot, maintain that these cells have migrated from the retinal mantle layer into the vitreous body. Seefelder proposes to call them ectodermal vitreous body cells (ektodermale Glasskörperzellen), and believes them to be identical with similar cells found later in large numbers in the mantle layer of the retina. Mavas and Magitot, moreover, are of opinion that, passing through a process of degeneration and disintegration, these cells contribute to the production of the liquid parts of the vitreous body. Wolfrum believes some to be real mesoderm cells with vaso-formative function, others he prefers to call ectodermal cells. The difference of opinion may, to some extent, be owing to the difference in the material used. In the material which formed the subject of our investigation, the cellular elements are exceedingly rare, scarcely half a dozen being counted in as many complete series of sections. In the eye of the pig, in which no mesoderm is carried into the optic cup by the lens

placode (Figure 6), and in which at this time no mesoderm has entered through the choroid fissure (Figure 1), it would be difficult to account for the presence of mesoderm in the vitreous body. In structure, the cells resemble the retinal cells. For these reasons, we incline to the belief, that they are of retinal origin and not mesenchyme. But whatever their origin and their nature may be, they show no connection with the vitreous body, nor do they at this stage of development contribute to the production of the vitreous fibers.

The vitreous body is represented in all embryos by a great mass of fibers, of which the larger portion extend radially between the retina and the lens, while, especially in embryos of 10 and 11 mm, some very prominent fibers are seen running approximately parallel to the retina and lens. It is not difficult to determine the origin of both. The radial fibers arise as long slender outgrowths from the conelike bases of the inner layer of retinal cells (Müller's supporting cells). Some can be traced directly from the retina to the lens, others are seen to send off branches in various directions which, dividing and subdividing, anastomose freely with branches from neighboring fibers, forming a dense reticulum in which further tracing becomes impossible. The fibers are slightly granular and react to the various stains in a manner not unlike that of the cytoplasm of their mother cells. In some sections, larger granules are found at the junction or branching points of the fibers, but their absence in the more perfect preparations, especially in the celloidin preparations, seems to show them to be artefacts, produced by precipitation. In the more perfect sections, the fibers appear almost homogeneous, slightly granular, tapering gradually from their broad bases at the retina to a slender thread near the lens. In the narrow isthmus between the anterior part of the retina and the lens, a very regular structure of the fibers is frequently found.

The radial fibers, however, are not restricted to the retina; the basal cells of the lens also send out a large number of them. These fibers differ widely from the retinal fibers. They are short and never traceable to the retina. At a short distance from the lens, they split into several branches which run almost parallel to the posterior part of the lens. At this point they are met by the more numerous and more massive retinal fibers, and together with them they form a thick, feltlike mass, especially observable in equatorial sections (Figures 1 and 8). The entire surface of the lens con-

tributes to the formation of these fibers, especially the cells opposite the region where retina and pigment layer meet. On the anterior surface of the lens, some of these fibers penetrate deeply into the surrounding mesoderm with which they frequently unite; others even find their way to the overlying body ectoderm. In the more advanced stages of development, when the lens capsule begins to be formed as a secretion of the lens cells, the lenticular fibers gradually lose their connection with the basal cells of the lens. The light space between the lens and the feltlike mass of fibers described above (Figure 1) signalizes the region of the future *tunica vasculosa lentis,* or vascular capsule of the lens.

The vitreous body at this stage of development, therefore, consists of fibers, both radial and parallel, which, springing from the conelike projections of the basal cells of the retina and lens, form with frequent anastomoses a dense network, or rather framework, constituting the solid or structural part of the vitreous body. These fibers arise solely as protoplasmic prolongations of the retinal and lenticular cells and are, therefore, ectodermal in their origin. No mesodermal elements contribute to their production.

We can not agree, therefore, with Schöler and his followers in their contention, that the vitreous body takes its origin from the mesoderm entering through the choroid fissure; for in all embryos, examined at the various stages of development up to 12 mm length, no mesoderm was found to have entered into the optic cup through the choroid fissure. The cells found here and there in the vitreous body, whatever their origin, nature, and ultimate fate may be, take no part in the production of the primitive vitreous body fibers, nor do they, at this stage, enter into any connection with them. The fibers can be traced so easily to the basal cells of the retina and lens that their retinal and lenticular origin respectively, at this stage of the development of the eye, admits of no doubt.

Cirincione maintains that these fibers are only temporary, and that their sole purpose is to fill out the cavity of the optic cup until the permanent vitreous body is formed by the mesoderm entering later through the choroid fissure. He admits the presence of the retinal and the lenticular fibers, and concedes their origin from the basal cells of the retina and lens, but regards them only as a *sostanza di replezione* destined to disappear in the same degree as the mesodermal elements advance into the cavity of the secondary optic vesicle to form the vitreous body (page 1,358). But further

investigation will show that this primitive condition of the vitreous body, although obscured and modified by the ingrowing mesoderm, remains essentially the same. A comparison of figures 2 and 19 shows rather that the mesodermal elements are only temporary structures in the vitreous body, which both in its primitive and in its final stage of development is purely ectodermal.

Neither do our observations agree with the views of Kessler that the vitreous body is an amorphous, gelatinous mass, the product of a process of transudation from the blood vessels (page 81). Its fibrous structure is so uniform, regular, and constant in all sections, whatever method is used in their preparation, that we can not regard the vitreous body as an amorphous mass. To dispose of the fibers as artificial productions of the reagents used in the preparation of the material, would be to do violence to fact.

By a careful study of the vitreous body in the sheep's eye, Van Pée arrives at the conclusion, that the radial fibers are, indeed, of retinal or ectodermal origin, but that the more prominent parallel fibers, which constitute the bulk of the vitreous body, are mesodermal in their origin, arising from the mesenchyme between the optic cup and the body wall. These fibers then pass through the narrow perilenticular opening and form the major part of the vitreous body. It is true, as will be seen from figure 2, that at a later stage of development numerous mesoderm cells with long protoplasmic outgrowths enter into the vitreous body, and the significance of this formation will be considered in its place, but it is equally true, that in the earlier stages, which are under consideration here, and which show the vitreous body in its primitive and simplest form, both the radial and the parallel fibers are exclusively the product of the basal cells of the retina and lens. In the eye of the pig, mesodermal vitreous fibers are not found at this stage of development.

Lenhossék, in a lengthy monograph, attempts to demonstrate that all the fibers constituting the structural parts of the vitreous body, are the product of the basal cells of the lens, and that the retina has no share in their production. All our preparations show the lenticular fibers first described by v. Lenhossék and later by his pupil, v. Szily. They are especially prominent in embryos of 10 and 11 mm length, radiating from all parts of the lens, and entering into communication with the retinal fibers, the extra-ocular mesoderm, and even with the body ectoderm. But we can not regard them as the exclusive structural parts of the vitreous body. It is

surprising that v. Lenhossék should have overlooked the more numerous, more massive, and more prominent fibers arising from the retina. The retinal fibers, moreover, are a permanent formation, as will appear from further study; the lenticular fibers are very early separated from their mother cells by the formation of the lens capsule, as v. Lenhossék himself points out. Wolfrum is of the opinion that the lenticular fibers serve as an apparatus for retaining the lens vesicle in its place after it has separated from the body ectoderm. The peculiar shape of the lens vesicle at this time seems to lend color to this theory. Whether or not the lens fibers contribute to the formation of the primitive vitreous body, their influence is neither predominant over, nor equal to, that of the retina, while after the formation of the lens capsule, no further connection exists between the lens and the vitreous body. Kölliker says of v. Lenhossék's theory: The lenticular vitreous body of v. Lenhossék does not exist (page 18).

The purely retinal, i. e., ectodermal origin of the primitive vitreous body, as described in this chapter, has found defenders in many modern investigators. It may suffice to mention Tornatola, Addario, Wolfrum, v. Szily, v. Kölliker, Mavas, Magitot, and Seefelder. Mavas and Magitot thus sum up the results of their investigation on the origin and the development of the vitreous body in the human eye: The primitive vitreous body is of retinal original. It consists of a very delicate fibrous mass, arising from the marginal zone of the embryonic retina. This marginal layer is formed by protoplasmic prolongations of the supporting cells, which are the first to differentiate in the inner layer of the optic vesicle. The primitive vitreous body is, therefore, an exoplastic formation of this layer (page 127).

II Period of Mesodermal Invasion of the Vitreous Body

The primitive simple condition of the vitreous body soon undergoes a radical change, brought about by the entrance of the complex hyaloid vascular system and numerous mesodermal elements. The relationship of these structures to the vitreous body is of paramount importance in judging of the true character and the further development of the latter.

The hyaloid artery, a branch of the *arteria centralis retinæ,* entering the optic cup through the still partly open choroid fissure, at first appears as a single solid trunk, pushing its way far into the

vitreous body (Figure 4). It soon gives rise to a number of branches which fill out the larger part of the space between the retina and the lens (Figure 2). Their tendency, however, is always towards the lens, which finally is completely surrounded by blood vessels furnishing it with nourishment during the period of its most rapid growth. Later there arises from the hyaloid artery near its entrance into the optic cup a second group of branches which radiate in all directions through the outer layer of the vitreous body near the retina. This condition is observable especially in embryos ranging from 35 to 100 mm in length (Figure 14). The larger part of the vitreous body of such embryos is again free from blood vessels.

A closer examination of the structure of the blood vessels shows that their walls are generally thin, consisting of a layer of endothelial cells to which a connective tissue cell is attached here and there. This structure is common to the main trunk as well as to all the branches of the hyaloid system at this time. Later, however, the main trunk of the hyaloid artery seems to be surrounded by an additional layer of cells enveloping the vascular endothelium like a mantle. This mantle layer has been classed by some authors among the neuroglia tissues of the central nervous system. Its intimate connection with the supporting tissues of the optic nerve, the structure and the epithelial arrangement of its cells, and the reaction of the latter to stains in a manner not unlike the neuroglia cells of the optic nerve, are said to prove the identity of this cell layer with the supporting tissues of the optic nerve (Mavas and Magitot, p. 129). For the eye of the pig, this structure has been described at length by Wolfrum (p. 249), to whom the interested reader is referred.

While Seefelder at first observed the neuroglia mantle around only the main trunk of the hyaloid artery, Mavas and Magitot found it enveloping not only the main trunk, but all the branches of the hyaloid system, thus interposing an ectodermal sheath of neuroglia tissue between the mesodermal elements of the blood vessels and the vitreous body and effectively preventing their union. According to these authors, therefore, the vitreous body is at this time free from all mesodermal admixture, and represents a purely ectodermal formation consisting of a framework of fibers, the product partly of the supporting tissues of the retina and partly of the neuroglia cells of the optic nerve. The vitreous body would then have to be regarded as a purely neuroglia tissue derived ultimately from the central nervous system (Mavas and Magitot, p. 132).

This simple solution of the complex vitreous body problem, however, meets with some difficulties in the subject under consideration here. The above-mentioned investigators arrived at their conclusion by the study of human material almost exclusively. But in the eye of the pig, the neuroglia mantle has been observed around only about one-third of the length of the main trunk of the hyaloid artery; it has never been shown to surround any of its branches. Our own observations agree fully with those of Wolfrum. A number of sections show the neuroglia mantle surrounding a portion of the hyaloid artery proper; but the branches exhibit only the usual vascular endothelium, which, as further investigation will show, enters into a close relationship with the vitreous body. This complex relationship between the vitreous body and the mesodermal elements of the blood vessels prevents our accepting, for the eye of the pig at least, the simple and attractive theory of the neuroglia origin and nature of the vitreous body.

But there are other elements found in the optic cup at this time of development which claim our attention. Together with the hyaloid artery, some free mesoderm cells likewise enter the optic cup and almost simultaneously we witness the invasion of the vitreous body by a large mass of mesoderm through the perilenticular opening (Figure 2). The function of these mesodermal elements has never been satisfactorily accounted for. Several circumstances, to which, as far as we know, attention has not yet been called, incline us to the belief that these mesoderm cells are primarily vaso-formative, aiding in the building up of the complex vascular system of the embryonic mammalian eye: 1. the invasion of the vitreous body by mesoderm is restricted to a comparatively short period of time, which corresponds to the period of the most rapid growth and expansion of the vascular system, and ceases as soon as the latter has attained its highest development (Figures 2 and 12); 2. while at first the mesodermal elements are found scattered throughout the larger part of the vitreous body, most of them soon congregate in the vicinity of the blood vessels, the rest of the vitreous body being at that time almost devoid of mesoderm; 3. that there exists some relationship between the vascular system of the vitreous body and the mesodermal elements, seems to be indicated also by the fact that in the eye of the birds, which even during embryonic development never contains blood vessels, the number of mesoderm cells is exceedingly small. Many authors even doubt the

presence of mesoderm in the chick's eye. Lillie says of these cells that "in character they resemble embryonic blood-cells and not mesenchyme, and disappear entirely by the eighth day" (p. 275).

That not all the mesoderm cells are, however, used in the formation of the blood vessels is evident from the fact that at all stages of development a number of them are found isolated in the vitreous body. It is not improbable, as some authors maintain, that these free mesoderm cells by a process of disintegration and degeneration contribute to the production of the fluid parts of the vitreous body. Accordingly, we have at this period of development two distinct mesodermal elements in the vitreous body, the mesoderm tissue of the blood vessels and a number of free mesoderm cells (Figure 13).

The question now arises as to what influence the hyaloid system and the free mesoderm cells have on the further development of the vitreous body. Do they modify the originally ectodermal nature of this tissue in such wise that we are forced to admit a mixed structure consisting of various parts, derivatives of both the outer and the middle germ layer?

It can not be denied that a close relationship arises between the fibers of the vitreous body and the walls of the blood vessels. The endothelium of the latter sends out a large number of fibers which penetrate into the surrounding vitreous body. They are short and delicate and never attain the massiveness of the vitreous fibers. Their purpose may be solely to secure a hold for the blood vessels in the loose surrounding tissue, a phenomenon not infrequently observed in embryonic structures. The retinal fibers, on the other hand, enter into direct union with the blood vessels. It is not difficult to trace many fibers in their entire course from the retina to the endothelial lining of the blood vessels, forming a protoplasmic bridge between the two. While the phenomenon can be observed at almost any stage of development, it is especially prominent in embryos ranging from 50 to 130 mm in length. Here at times we see the fibers apparently radiating from the blood vessels like the radii of a wheel (Figure 14). It is probable that in this way nutriment is carried from the blood vessels to the vitreous body and also to the retina, which for a long time is deprived of a vascular system of its own.

A. v. Szily, who has devoted much labor to the study of this peculiar phenomenon of the concrescence of ectodermal vitreous

body fibers and mesodermal endothelial cells, maintains that the retinal fibers after entering into a union with the mesoderm, lose all connection with their mother cells of the retina, and become structurally as well as functionally dependent on the endothelium of the blood vessels. We should thus have the unique case of an ectodermal structure separating from its parental tissue and entering into functional dependence on a mesodermal structure, a phenomenon unparalleled in embryonic development. While it is true, that in the inner portions of the optic cup, with progressive differentiation, the retina loses the faculty of producing vitreous fibers, this does not hold of the retina in its whole extent. In embryos of 25 and even 35 mm length, which marks the height of development of the vascular system, the greater part of the vitreous fibers is still in connection with the retina, while throughout the whole course of embryonic development, and even in the fully developed eye, the vitreous body fibers remain united with the retina in the region of the *pars ciliaris sive coeca retinæ*. There the vitreous body never separates from the basal cells of the retina to which it owes its origin. This may be readily seen by comparing the corresponding sections of the eyes of embryos of 25, 35, 60, 80, 100, 130, 175, and 250 mm length. As the study of this part of the retina, at various stages of development, throws much light on the development and the ultimate structure of the vitreous body, we have reproduced a number of these both by sketches and by photographs. A close study of these also refutes the theory of v. Lenhossék that the vitreous body, separating from its place of origin, the basal cells of the crystalline lens, forms a syncytium, deprived of cellular elements, and capable of independent growth, development, and nutrition. Even in those regions where the retina loses the faculty of producing vitreous fibers, there is no clear separation between the two. The vitreous body even there retains its intimate connection with the internal limiting membrane of the retina by a great number of very delicate fibrils, which form the ragged edge of the vitreous body in sections where shrinkage has pulled the two apart.

That the vitreous body fibers also enter into close relationship with the free mesodermal elements found in the vitreous body is made clear by many sections. After the manner of embryonic connective tissue cells, many of the mesoderm cells assume a stellate or fusiform shape and send out protoplasmic processes of greater or shorter length. From these not infrequently long slender threads

arise which attach themselves to any structure within reach, whether other mesoderm cells or blood vessels or vitreous body fibers. There seems to be no doubt that the latter also enter into direct union with the mesoderm cells. We have thus an extremely complex relationship between retinal fibers, blood vessels and free mesoderm cells. We would emphasize this fact in view of the contention of Mavas, Magitot, and Seefelder, that the mesodermal elements present in the vitreous body are hermetically shut off (Seefelder) from the latter, thus excluding the possibility of mesodermal contributions to the vitreous body.

In view of the complex relationship between ectodermal and mesodermal elements in the vitreous body, we agree with v. Szily that the "vitreous body problem" is not so much to decide its origin, which at the present time is almost universally regarded as ectodermal, but to determine the influence of various mesodermal structures upon its further development. Szily puts the question on a wider basis in so far as he maintains the real point at issue is the union of two structures, primarily derived from different germ layers, into one tissue. While all our preparations of many stages of development of the eye of the pig, reveal this complex union of mesodermal and ectodermal derivatives in a clear and unmistakable manner, we are not prepared to follow v. Szily in asserting that the ectodermal vitreous body fibers become also functionally dependent on the mesoderm. It is the retina which gives rise to the primitive vitreous body; it is the retina which directs and controls the development of its structural parts; it is the retina which in the fully developed eye contributes exclusively to the formation of the vitreous body. The retina alone never loses its original relationship to the vitreous fibers; upon the retina they are structurally and functionally dependent in their origin, development, and final arrangement. Though this intimate relationship between retina and vitreous body is found at first in the whole extent of the retina, it is, however, later restricted to a narrow circular strip of the retina between the *ora serrata* and the *pars ciliaris retinæ* proper. There the controlling influence of the retina upon the vitreous body fibers is manifest at every stage of development as well as in the eye of the adult animal.

Our conception of the relationship between retina and vitreous body finds a singular confirmation in the results of experiments made by Haemers to determine whether regeneration of the vitreous

body is possible and how it takes place. After a number of experiments on the eyes of various animals, Haemers asserts that "the vitreous body regenerates at the expense of the retinal neuroglia" (page 114). But surely, the regeneration of one tissue from another presupposes a relationship of dependence between them. It is to be regretted that Haemers has not found any followers in his ingenious attack upon the vitreous body problem by a careful study of the process of regeneration. No doubt, a repetition and extension of Haemers' investigations would tend to clear up other difficulties and point the way for a final solution of this interesting and difficult problem. Regeneration of the vitreous body has been observed also by Sauri.

During the period of development described in this chapter, the general appearance of the vitreous body has greatly changed even in the regions not directly affected by the invasion of the mesoderm. While during the earlier stages, including embryos of 35 mm length, the radial fibers still form the larger part of its structure, we soon observe that they are more and more replaced by fibers running approximately parallel to retina and lens. The parallel fibers are at first found in the exterior regions of the vitreous body near the retina, where they gradually assume the appearance of a special membrane, distinct from the internal limiting membrane of the retina, and forming the outer covering of the vitreous body. It has been generally called the hyaloid membrane. Later a number of fibers are found to take their course from the region anterior to the *ora serrata* to the posterior part of the lens and then turn inward in the direction of the optic nerve. They represent the first traces of a more solid portion of the anterior surface of the vitreous body, and they have sometimes been called the anterior hyaloid membrane. The discussion of the significance of these structures will be reserved for the next chapter.

Our conclusions, derived from the study of this most important period in the development of the vitreous body, may be summed up thus: The original purely ectodermal structure of the vitreous body is radically changed by the accession of various mesodermal elements in the form of blood vessels and free mesoderm cells with their outgrowths. The ectodermal vitreous fibers enter into a close relationship with the mesoderm, the relationship being one not only of contiguity but of protoplasmic continuity, consisting of a protoplasmic union between them. This union, however, does not de-

prive the retina of its controlling influence in the further development of the vitreous body, which throughout remains functionally dependent on it. The vitreous body, therefore, at this stage of development is a very complex structure, the constituent parts of which are partly ectodermal and partly mesodermal in their origin.

III The Permanent Vitreous Body

The structure of the vitreous body described in the preceding chapter, is not a permanent one. The hyaloid vascular system, having fulfilled its function of supplying nourishment to the crystalline lens, soon shows signs of degeneration and gradually disappears. The remnants of the mesodermal cells begin to disintegrate and dissolve. The vitreous body then appears again in its original purity, modified indeed and greatly changed, but in its essentials like the primitive ectodermal vitreous body. An excellent representation of its general appearance and internal structure is found on plate VI, showing various portions of the eye of a fetus 220 mm in length.

Figure 17 represents a horizontal section of the eye, passing through the optic nerve and the lens in a plane parallel to the hyaloid artery, and bisecting the hyaloid canal. The lens has been slightly displaced in the act of sectioning, causing some disarrangement of the adjacent structures, especially of the fibers of the zonula ciliaris. The vitreous body, however, is in perfect condition. The section was stained in Held's molybdic haematoxylin, which shows very clearly the delicate fibers, but unfortunately overstains the remaining structures. The small crystals found scattered here and there are owing to mercuric chloride used in killing and fixing the material.

The salient feature of the vitreous body at this period of development, compared with figure 5, is the absence of the large mesodermal ingredient of the previous stages of development. All that remains of the extensive hyaloid arterial system is the main trunk, the hyaloid artery, extending through the entire posterior chamber of the eye, from the optic nerve to the lens, to which it still adheres. Its various branches have already disappeared. A closer examination of the vitreous body, however, reveals a large number of cells in various stages of disintegration. The methods used in the preparation of the material and the heavy stain make it impossible

to determine the structure and the nature of these cells, but nowhere does there appear any connection between them and the vitreous body fibers.

The vitreous body proper is represented by a great mass of very delicate fibers, arising exclusively from a small region of the anterior portion of the retina, the *pars coeca retinæ*. From here they descend in fairly heavy bundles towards the center of the bulbus in the region of the optic nerve. Several of these fiber bundles pass closely along the retina, while the others grow slightly inward in the direction of the lens and then turning backward join the first near the optic nerve (Figure 18). Between these two heavier portions of the vitreous body we have a rather large space filled with an irregular mass of fibrous tissue. The vitreous body, therefore, is composed of two rather prominent masses or layers of fibers, the one forming the outer portions near the retina, and the other lining the hyaloid canal, while the intervening region contains a very loosely arranged fibrous mass. The outer portion of the vitreous fibers has been quite generally held to be a special membrane and called the hyaloid membrane. Careful investigation shows that the vitreous fibers are, indeed, more closely arranged in this region, but they do not coalesce to form a distinct membrane. The internal limiting membrane of the retina seems rather to be common to both the retina and the vitreous body. This view is held by most recent investigators (Kölliker, Szily, Wolfrum, Mavas, Magitot, Seefelder, Szent-Györgyi), who insist that the supposition of the existence of a membrane enveloping the vitreous body and distinct from the internal limiting membrane of the retina is not based upon fact. In this connection we may call attention to the peculiar fact that, when shrinkage of the vitreous body takes place, the retinal membrane quite generally adheres to the vitreous body, which shows the intimate union of the two. The inner mass of vitreous body fibers separates the vitreous body proper from the so-called hyaloid canal. This portion of the vitreous body, the existence, size, and real structure of which have been the subject of much controversy, is clearly shown in figure 18.

Figure 17 shows its relation to the other parts of the eye, its relative size and its shape. It roughly resembles a funnel, with its mouth towards the lens, and the stem surrounding the optic papilla. While quite narrow in the inner portion of the eye, it widens very much

and extends not to the lens, but to the ciliary portion of the retina, which gives rise to the vitreous fibers. Its vast size, compared with the diameter of the hyaloid artery, seems to dispose at once of the theory that the hyaloid canal simply represents the portion of the vitreous body formerly occupied by that blood vessel. Its walls are formed by the vitreous fibers which in many sections have all the appearances of a real membrane (Figure 18). This impression is heightened by closer study. Still we hesitate to describe this portion as a special membrane. We rather incline to the belief that the membranous appearance is owing to the thickness of the section, which in this case is not less than 400 microns. The fibrous nature of this structure seems to be quite plainly shown in the upper left-hand portions of figure 18. It is not improbable, however, that the fibers are held together by the thickened fluids of the vitreous body, giving it the firm membranous appearance it possesses. This portion of the vitreous body, although generally called the hyaloid canal, is in reality not a canal. It is not an open tube without structural elements, because its interior is filled with an irregular mass of tissue, not unlike that of the central portions of the vitreous body enclosed between the outer and inner fiber bundles already described and illustrated in figure 18.

To complete the description of the eye at this period we call attention to another new structure which has appeared in the mean time, the zonula ciliaris (Figure 15). The sketch is prepared from a section of the left eye of the same embryo which furnished the material for the illustrations on plate. The zonula ciliaris consists of a number of rather strong fibers between the pars ciliaris retinæ and the lens. They arise, as is clearly shown in many sections, from the region of the retina, that produces the vitreous fibers, only slightly anterior to the latter. Retina, vitreous body, and zonula ciliaris, therefore, are genetically most intimately related.

Keeping in mind the structure of the eye at this rather advanced stage of embryonic life, we may now attempt to trace the development of the various parts of the vitreous body up to this time. In embryos of 80 mm length, the hyaloid vascular system consists of the main trunk and a number of branches, some of which surround the posterior half of the lens, while the rest form a complex system in the outer portion of the vitreous body near the retina. The entire system is only a temporary formation, whose function is to furnish nourishment to the rapidly developing lens, and no doubt,

also to the vitreous body and to part of the retina, which for a long time has no blood vessels of its own. This functional interdependence of blood vessels, vitreous fibers, and retina might offer a teleological explanation for the intimate protoplasmic union of these parts described in chapter II. As soon as the hyaloid system has discharged this nutritive function, a process of resorption sets in. This process does not always begin from the extremities of the branches; it first manifests itself by a general decrease in the diameter of the blood vessels, which may thus be cut up into a number of parts found scattered in various places of the vitreous body. These parts gradually disintegrate and give rise to many cellular elements which are met with in more advanced stages of development and sometimes even in the eyes of adult animals. They are the remnants of the hyaloid vascular system. The gradual resorption of the blood vessels does not proceed in a uniform manner in all embryos, as a comparison of embryos of 130, 150, and 180 mm length shows, but in the eyes of embryos of 200 mm, only the main trunk, the hyaloid artery proper, remains (Figure 17). It may be added here that the main trunk was found also in a practically mature fetus 12 inches in length, which makes it probable that complete resorption of the hyaloid artery takes place at the time of birth or even later. In the eye of a full grown animal, a piece of the hyaloid artery, about 6 mm long, was still present attached to the lens. Together with the hyaloid system the remaining mesodermal elements also undergo a process of disintegration.

What then is the fate of the fibrous network which we found in such intimate union with the mesoderm in the previous stages of development? It is probable that a portion of it also disintegrates and is resorbed. But it is no less probable that the remaining portions make up the loose fibrous tissue found in the hyaloid canal and in the more fluid parts of the vitreous body. The reasons for this assumption will be given below.

We must first turn our attention to another structure, a clear conception of the formation and the significance of which will throw more light on the present investigation. This structure is the hyaloid canal. We have already called attention to the wide difference in the diameter of the hyaloid artery and the so-called hyaloid canal, and expressed our doubts that the latter represents nothing but the cavity left for a time after the former has been resorbed. This

explanation is defended most persistently by Wolfrum, who maintains moreover that the hyaloid canal is not found in the eyes of adult animals, except in connection with remnants of the hyaloid artery. The discussion of the latter statement we reserve until later. For the embryonic eye, however, we can not accept Wolfrum's explanation.

Equatorial sections prepared for the purpose of ascertaining the precise time of the first appearance of the hyaloid canal show that it is formed in embryos between 130 and 150 mm length. From the first it shows its characteristic funnel-like shape, its size considerably exceeding the diameter of the blood vessel (Figure 20). The latter most frequently appears in the center of the canal and shows no relation to its walls (Figure 18). In a number of longitudinal sections of the eyes of embryos ranging from 150 to 180 mm length, the slowly degenerating hyaloid system consists of the main trunk, the hyaloid artery, and several branches surrounding it in a manner not unlike the supporting framework of a tent. At this time there is observed likewise an increased growth of the vitreous fibers from the ciliary region of the retina. A portion of these fibers, as was shown above, takes its course toward the lens and then turns inward toward the centre of the eye. It is this portion which is so prominent in figure 18. Now it seems to us very probable that this peculiar direction is given to the fibers by the branches of the blood vessels. In many sections, parts of the latter are almost invariably found in a plane parallel to the vitreous fiber bundles (Figure 21). But whereas the blood vessels finally disappear, the direction given to the fibers remains, thus determining the outline and shape of the hyaloid canal of which they form the membrane-like wall.

This denser formation of the vitreous fibers, descending in a circular band from the ciliary retina encloses a large portion of the original vitreous body which forms the fibrous contents of the hyaloid canal. This irregular fibrous mass may, therefore, be regarded as the remnant of the central portion of the vitreous body of the preceding period of development. A similar explanation is offered for the irregular fibrous tissue between the two heavier layers of vitreous fibers in the lateral parts of the eye. Thus the hyaloid canal is not a canal in the generally accepted meaning of the word, yet it possesses such a definite structure, and it is so sharply marked off from the rest of the vitreous body that it deserves a special

name. "Hyaloid portion of the vitreous body" might be more descriptive of its real structure. Szent-Györgyi suggests *tractus hyaloideus corporis vitrei.* Its essential structure is given at this stage of development; only minor modifications are observed in the eye of the adult animal.

The description of the formation of the hyaloid canal leads us also to a better appreciation of the structure of the vitreous body as a whole. The complex structure of the preceding period, owing to the invasion by great masses of mesoderm, has disappeared through a process of disintegration and resorption, and has given place to a much simpler and more regular arrangement of the fibers. The rather strong fibers of the pars ciliaris, already observed in embryos of 60 and 80 mm length, have in the meantime assumed the appearance of fiber bundles (Figure 19), the arrangement of which has already been described at length. There is no longer evidence of an extensive union between these fibers, each bundle being more or less independent of the others. But their place of origin is the same, the cells of that portion of the ciliary retina, immediately anterior to the *ora serrata.* The ectodermal origin and nature of the permanent vitreous body is, therefore, no less certain than that of the primitive vitreous body. The mesoderm has no share in its production.

The vitreous body in the eye of the adult animal differs only in minor details from that described so far. Comparing figures 17 and 19, we notice that the hyaloid artery has entirely disappeared. The fibers of the vitreous body and the zonula ciliaris have essentially the same arrangement and structure (Figures 15 and 16). The shape of the hyaloid canal, however, has slightly changed. By a further ingrowth of the vitreous fibers in the region of the lens, the funnel-like shape of the preceding stages (Figures 17 and 18) has given place to a structure of almost uniform diameter throughout its entire length (Figures 19 and 22). This tissue, however, shows no tendency to condensation or growth which might lead to a gradual obliteration of the canal. The latter was found in the eyes of every specimen examined, forty in all. Wolfrum's statement, therefore, that the hyaloid canal is not a constant structure of the eye of the adult pig, but is found only occasionally and then always in connection with remnants of the hyaloid artery, is not in accordance with the facts. Only in two eyes, out of a total of

forty, were traces of the hyaloid artery found, and even in these two the independent formation of the hyaloid canal was plainly shown.

Our own results may be summed up thus: the hyaloid canal, or the hyaloid portion of the vitreous body, formed by a denser arrangement of the vitreous fibers and including a loose and irregular fibrous tissue, is a constant structure in the eye of the adult pig. It is of almost uniform width throughout, and extends through the entire posterior chamber of the eye from the optic disc to the lens, from which it is separated by the thin membranelike lining of the *fossa patellaris*. In rare cases it contains remnants of the hyaloid artery, which, however, show no relationship to its walls. The hyaloid canal in the eye of the adult pig, is, therefore, not a temporary formation nor is it to be attributed to the hyaloid artery.

Szent-Györgyi, who has made extensive investigations of the structure of the hyaloid canal in the eyes of adult animals, including the pig, maintains that the relationship of the vitreous body fibers to the ciliary portion of the retina is a secondary formation, attributable to the tendency of the vitreous fibers to attach themselves to any structure near them, and that in consequence this relationship does not warrant a conclusion as to the origin of these fibers, which must be sought rather in the vitreous body itself with its native faculty of growth and differentiation. But it is plain that the structure of the adult eye does not of itself reveal whether the conditions found there are primary or secondary. Nor is it always safe to attempt the reconstruction of the ontogeny of a species from its supposed phylogenetic development. Only the careful study of the various phases of embryonic development shows whether the union between the vitreous fibers and the ciliary retina is a secondary formation or has genetic significance. A comparison of figures 8 and 19 reveals at once the untenability of Szent-Györgyi's opinion, and disposes at the same time effectively of the view of Lenhossék, adopted and modified by his brilliant followers, v. Szily and Szent-Györgyi, that the vitreous body, separating from its place of origin, becomes a syncytium, capable of independent nutrition, growth, differentiation and regeneration. The union between the vitreous body and the ciliary retina can be traced uninterruptedly from the first appearance of the vitreous fibers to the formation of the permanent vitreous body. The latter, therefore, no less than

the primitive, and the essential portions of the secondary vitreous body, are a purely ectodermal derivative.

CONCLUSIONS

1. The vitreous body in its origin is a purely ectodermal structure and consists of delicate fibers, the protoplasmic outgrowths of the basal cells of the retina.

2. With the development of the hyaloid vascular system and the accession of other mesodermal elements, an intimate union arises between the vitreous body fibers and the mesoderm, so that the vitreous body at that stage of development must be regarded as a tissue of derivatives of both the outer and the middle germ layer.

3. The union between the vitreous body and the mesoderm does not destroy the dependence of the vitreous fibers upon the retina, which during the entire embryonic life controls the development of the vitreous body.

4. The union of the vitreous body and the mesoderm is not permanent. It is dissolved with the gradual resorption of the hyaloid vascular system and the disintegration of the remaining mesodermal elements.

5. The vitreous body in its final development is again a purely ectodermal structure, consisting of great masses of delicate fibers, which have their origin in the basal cells of the ciliary portion of the retina.

6. There is no hyaloid membrane distinct from the internal limiting membrane of the retina.

7. The hyaloid canal, or rather the hyaloid portion of the vitreous body, is found in all advanced stages of development and in the eye of the adult animal.

8. The hyaloid canal is formed by a thick, membranelike mass of vitreous fibers and contains a loosely arranged fibrous tissue, which may be regarded as the remnant of the secondary vitreous body.

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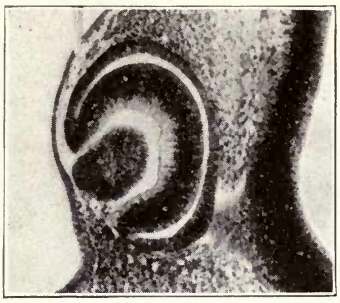
EXPLANATION OF THE FIGURES



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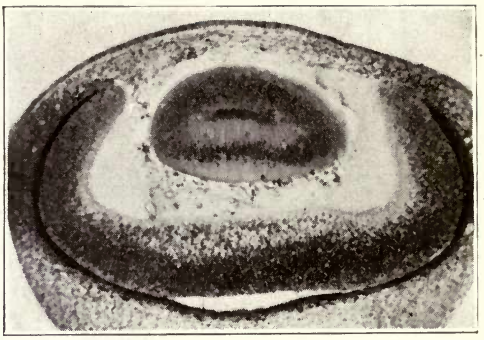

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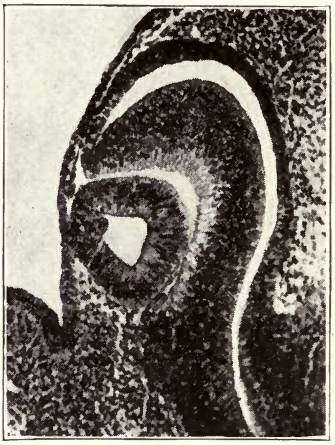

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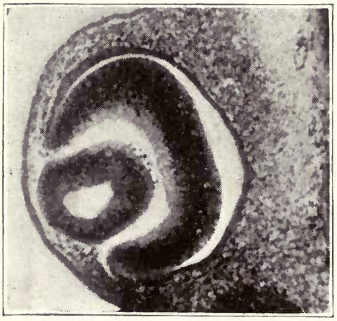

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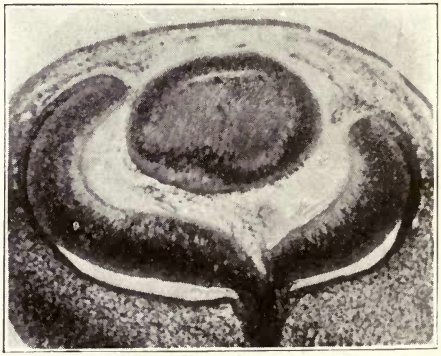

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PLATE I.

A. W. Fromm photog.

PLATE I.

Figures 1, 2, 4 and 5 were magnified 100 diameters, figure 3 was magnified 150 diameters, the entire plate was then reduced to two-thirds in reproduction.

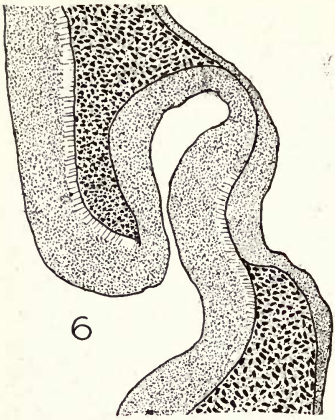
Fig. 1. Longitudinal section of eye of 9 mm embryo. The section is slightly posterior to the optic stalk, a part of which is shown between pigment layer and portion of the diencephalon visible to right.

Fig. 2. Longitudinal section of eye of 20 mm. embryo. The section shows plainly the connection between the vitreous body and the extraocular mesenchyme, which is invading the optic cup through the perilenticular opening; also extensive vascular system and considerable differentiation of central portion of retina.

Fig. 3. Longitudinal section of eye of 8 mm embryo. Lens vesicle complete, choroid fissure wide open, mesenchyme pressing into optic cup through choroid fissure.

Fig. 4. Horizontal section of eye of 12 mm embryo. Hyaloid artery has penetrated to lens vesicle.

Fig. 5. Longitudinal section of eye of 25 mm embryo. Hyaloid artery entering through optic stalk, has given rise to extensive vascular system which penetrates larger part of vitreous body.



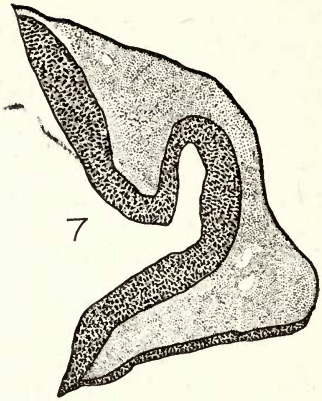


PLATE II.

Fromm & Herring del.

PLATE II.

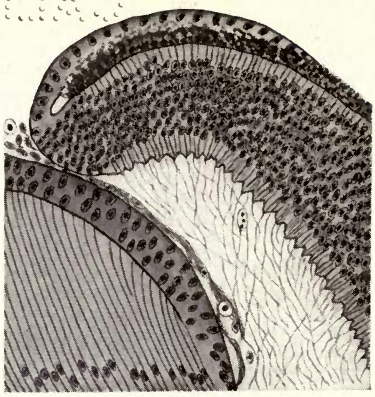
Figures 6-9 were drawn with a camera lucida, Bausch and Lomb microscope, ocular 10, objective 4. Plate reduced to two-thirds in reproduction.

Fig. 6. Longitudinal section of eye of 5 mm embryo. First stage in the formation of the optic cup and the lens vesicle.

Fig. 7. Longitudinal section of eye of 3.5 mm embryo, showing primary optic vesicle. Note layer of mesenchyme between optic vesicle and body ectoderm.

Fig. 8. Detail of section of eye of 9 mm embryo.

Fig. 9. Detail of longitudinal section of eye of 11 mm embryo, showing general arrangement of vitreous fibers.



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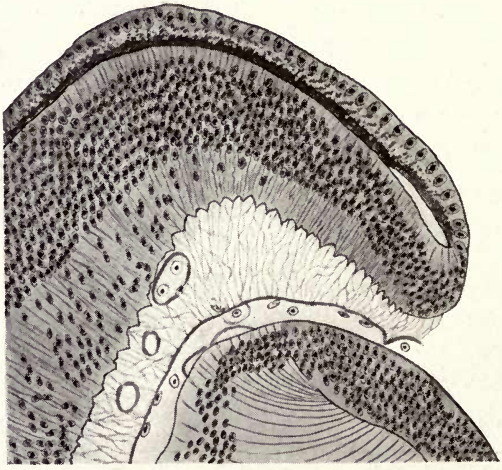

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PLATE III.

Fromm & Herring del.

PLATE III.

Figures 10-12 were drawn with a camera lucida, Bausch and Lomb microscope, ocular 5, objective 16. Plate reduced to one-half.

Fig. 10. Detail of section of eye of 25 mm embryo.

Fig. 11. Detail of section of eye of 80 mm embryo.

Fig. 12. Detail of section of eye of 35 mm embryo.

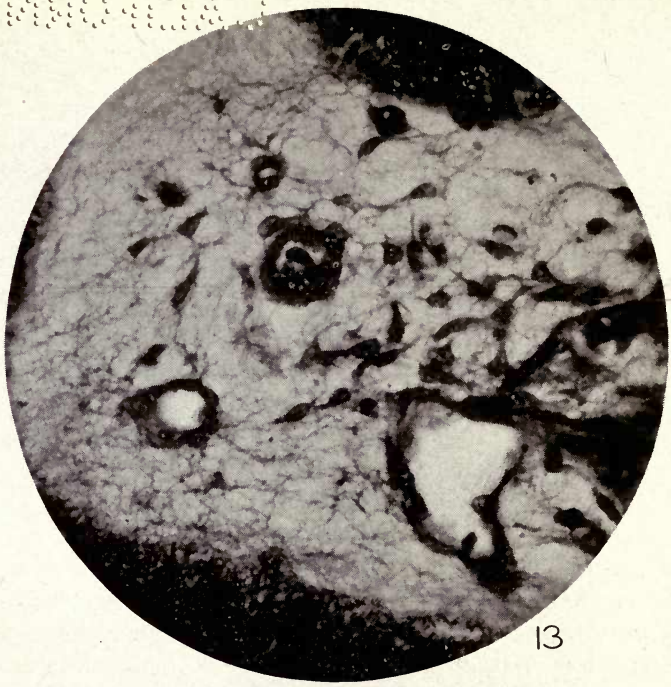


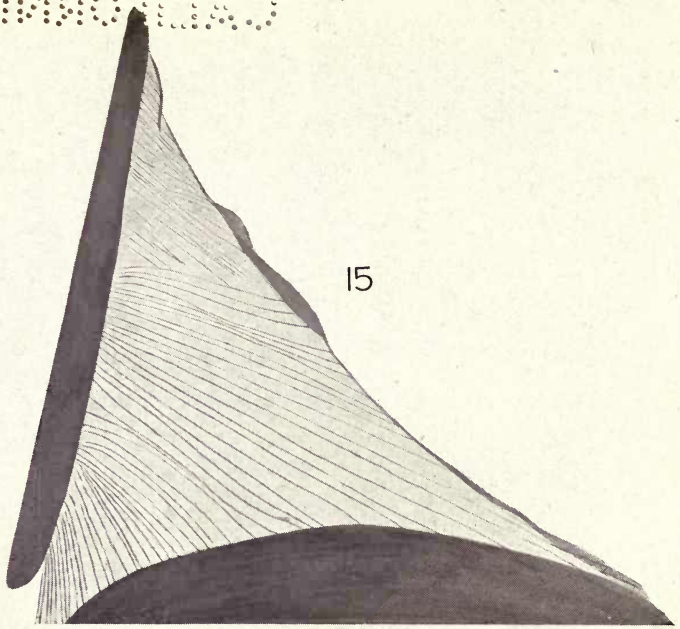
PLATE IV.

A. W. Fromm photog.

PLATE IV.

Fig. 13. Cross-section of vitreous body of 23 mm embryo, showing the many fibrous outgrowths of the hyaloid arterial system and of the numerous free mesoderm cells, also the union of these mesodermal elements with the vitreous body. Magnification 350 diameters.

Fig. 14. Section of eye of 100 mm embryo. Blood vessels form two distinct systems, one surrounding the lens, and the other lying close to the retina. Numerous fibers of blood vessels. Note especially fibers running parallel to retina. Magnification 95 diameters.



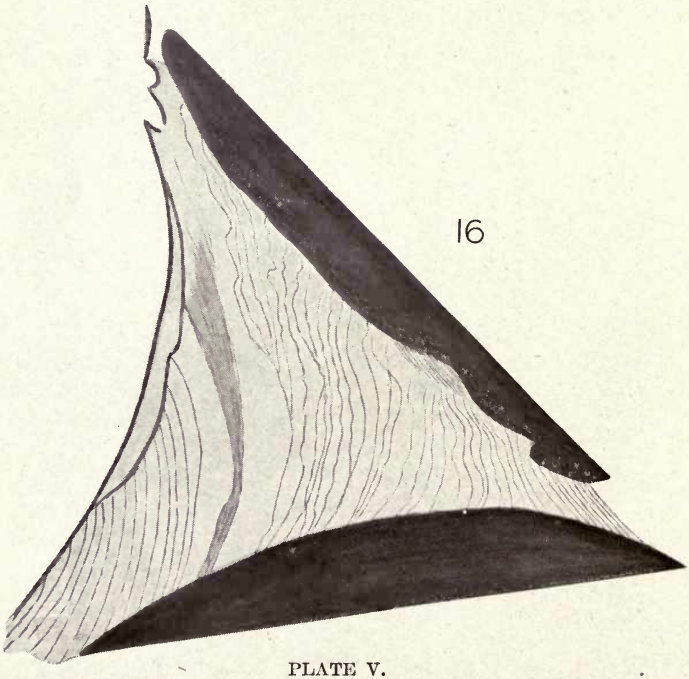
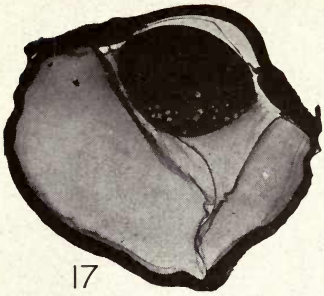


PLATE V.

Fromm & Herring del.

PLATE V.

Figures 15 and 16. Zonula ciliaris of eye of 225 mm embryo and of adult animal. Drawn with camera lucida, Bausch and Lomb microscope, ocular 5, objective 16. Plate reduced to two-thirds. Portion of lens (below) and of ciliary retina.



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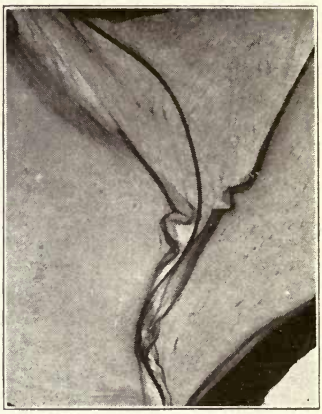

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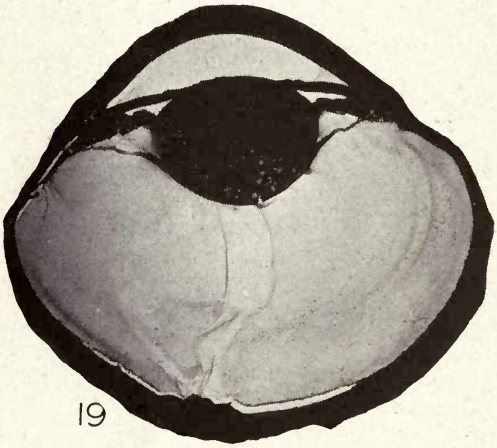

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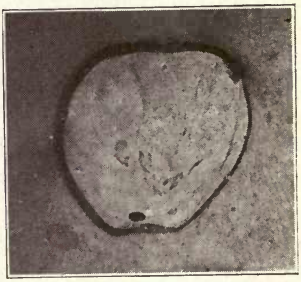

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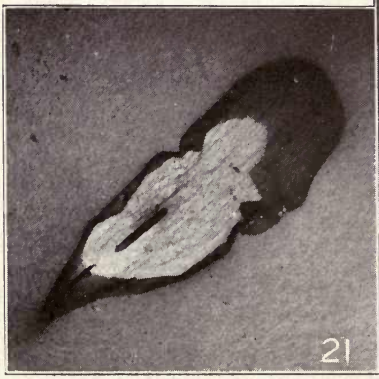

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PLATE VI.

A. W. Fromm photog.

PLATE VI.

Fig. 17. Horizontal section of eye of 225 mm fetus, showing hyaloid canal with hyaloid artery, and origin of vitreous fibers from ciliary retina. Magnification 6 diameters.

Fig. 18. Central portion of fig. 17 further enlarged.

Fig. 19. Horizontal section of eye of adult pig, showing hyaloid canal, vitreous fibers, and zonula ciliaris. Magnification 2.5 diameters.

Fig. 20. Cross-section of hyaloid canal of 250 mm fetus, with hyaloid artery in lower centre. Magnification 20 diameters.

Fig. 21. Cross-section of hyaloid canal of 150 mm embryo. Magnification 20 diameters.

Fig. 22. Cross-section of hyaloid canal of eye of adult pig. Magnified 20 diameters.

VITA AUCTORIS

The writer of this dissertation was born in Volkerode, in the Province of Saxony, Germany, March 26, 1883. After attending the public school of his native town for seven years, he came to this country in 1895 and entered St. Joseph Seminary, Teutopolis, Illinois, from which he was graduated in June, 1902. In the same month he entered the Order of Friars Minor in the Province of the Sacred Heart, pursuing his rhetorical and philosophical studies in Chicago, Illinois, from 1903 to 1906, and his theological studies in St. Louis, Missouri, from 1906 to 1910. He was ordained to the holy priesthood on June 25, 1909. From 1910 to 1917 he was a member of the faculty of St. Joseph Seminary, Teutopolis, Illinois. He then spent two years at the University of Chicago in the study of biology, physiology, and psychology, and three semesters at the Catholic University of America, Washington, D. C.